IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of:)	Confirmation No, 5574
)	
Thomas Rex Haskell)	Examiner Tajash D. Patel
)	
Serial No.: 10/522,459)	Group Art Unit 3763
)	
Filed: 1/24/2005)	
)	
For: ENERGY ABSORBING GARMENT)	
)	

DECLARATION UNDER RULE 1.131 SWEARING BEHIND REFERENCE

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

I, Thomas Rex Haskell, the above named inventor declare as follows:

1.   I am the inventor of the above entitled ENERGY ABSORBING GARMENT.

2.   I conceived and reduced to practice in New Zealand, a WTO country since 1996, my invention entitled ENERGY ABSORBING GARMENT described in the above identified application prior to February 2001.

3.   The conception and reduction to practice prior to February 2001 is evidenced by the attached Feasibility Study on the ENERGY ABSORBING GARMENT prepared by Industrial Research Limited of Auckland New Zealand for my company, Rhumbline Limited, which Feasibility Study Report was completed in February 2001.

4.   A prototype of my ENERGY ABSORBING GARMENT is shown in FIG. 4.3 on page 9 of the Feasibility Study.

5.   Based on the above and attached evidence of my conception and reduction to practice of my invention entitled ENERGY ABSORBING GARMENT at least as early as February 2001, I

herby swear behind the earliest filing date of March 28, 2002, of the Gathings Jr. U.S. Patent No. 6,907,619.

I herby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the subject patent application or any patent issuing thereon.

Date   07/07/08

Thomas Rex Haskell

Industrial Research Limited Report 91724.01.02

INDUSTRIAL RESEARCH LIMITED

Feasibility Study of Energy Absorbing Equestrian Rider Protection Systems

Report prepared for
Rhumbline Limited

by

Dr Mark Battley

Industrial Research Limited
Auckland
February 2001

1. Contents

2. Introduction

This report summarises the results of a theoretical and experimental investigation performed by Industrial Research Limited into the feasiblity of a body armour protection concept proposed by Rhumbline Limited. The aim of the project was to determine if the concept was feasible, and to provide the basis for a subsequent project to develop a production prototype. The work was performed under the Technology For Business Techlink scheme.

Conventional equestrian protection clothing is based on 15-20 mm thick polystyrene blocks arranged in the manner of a conventional buoyancy aid. These blocks have the ability to progressively absorb impact energy and spread it over the body. They are considered by users to be hot, bulky and inflexible, reflecting the normal insulating application of the core material, and juxtaposition of the essentially rigid blocks.

The system to be evaluated in this project relies on progressive deformation of resilient asymmetrical plates. These plates are arranged as shown in Figure 2.1 to overlap 50% of their area on a longitudinal axis within a flak-jacket type of garment.
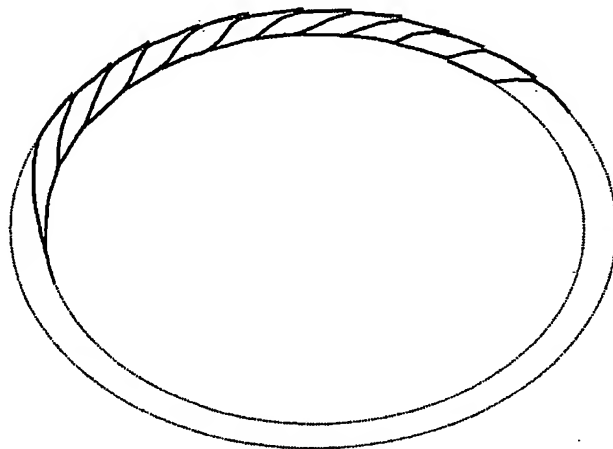

Figure 2.1 Plan view of Plate Arrangement on Thorax of rider

Figure 2.2 shows the front and side views of the plates. This positioning of separate plates allows impact loading to spread to adjacent plates progressively absorbing and spreading impact energy in a more effective manner. The system has similar overall bulk to the existing design, is lighter and can be ventilated by means of perforations and cut-outs. The plate arrangement easily accommodates flexure, particularly torsion flexure and also offers some spinal and kicking impact protection, which is beyond the capacity of current systems.
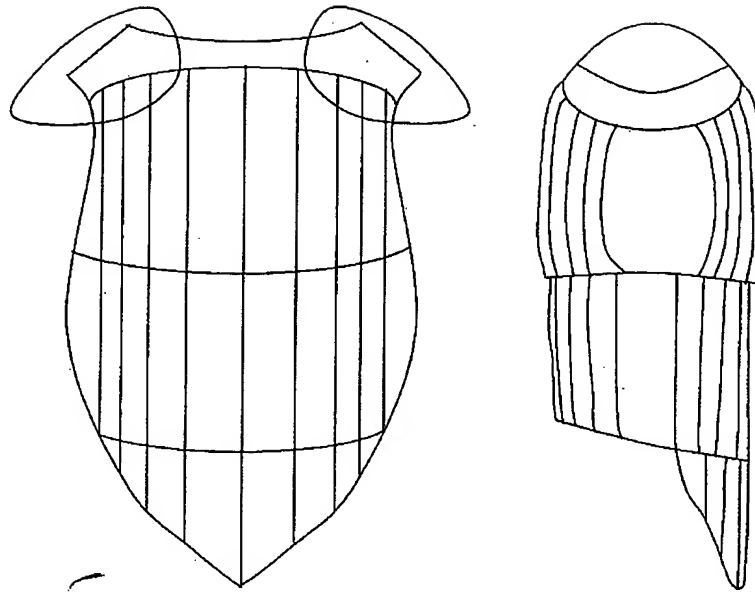
Figure 2.2 Plate arrangement- front and side views

The commercial benefits of this development lie in the plate system's potential to provide a product that gives better protection than products currently available, and that is more comfortable for riders to wear.

The primary technical aims of this part of the overall project were to:
- Perform a simple theoretical assessment of the energy absorption capability of the proposed concept
- Establish an experimental system capable of performing impact tests on protection systems
- Manufacture sample plates representative of the proposed new system
- Perform experimental impact tests on an existing foam based protection jacket and the proposed new system.

3. Predictions

A Microsoft Excel-based calculation spreadsheet was developed to predict energy levels required to deform an initially curved plate to a final flat shape. The method is based on a simple beam theory and pseudo-static loads, and uses material stiffness and strength properties, plate dimensions, and curvature as inputs. The model considers three stages in the loading of the curved panel; a linearly increasing load during the initial elastic loading of the plate (calculated from the beam's bending properties), then a constant force stage during material yield (simplified to a straight horizontal line), and finally a third area where the theoretical failure of the beam is predicted from the maximum strain value of the outer layer. The area contained by the lines represents theoretical energy absorbed by the plate when deformed to a flat shape.

Figure 3.1 shows a typical results graph from the spreadsheet. It shows three zones: on the left, the rising curve is the elastic loading of the plate, calculated from the beam's bending properties, then the yield behavior, which was simplified to a straight horizontal line. The third area, delimited by the dotted line considers the theoretical failure of the beam, using a maximum strain value of the outer layer. The area surrounded by these lines represents theoretical energy absorbed by the plate. the last vertical line on the right represents the maximum deflection of the plate (when flat).
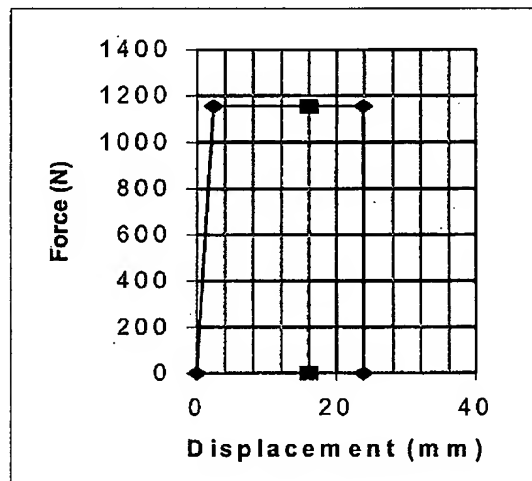

Figure 3.1 Typical predicted force/displacement graph

The spreadsheet was used to evaluate possible materials and geometries that would be able to absorb the required 50J of energy required by the BETA standard [1]. The results of the study suggest that according to this simplified model it should be possible to design plates to absorb the required energy that have acceptable dimensions. Key findings include:

- The plates should use relatively thick (several mm), low modulus materials (such as plastics or composites with low levels of fibre reinforcement) rather than thin high modulus materials such as aluminium.

- Plates that are designed to deform plastically should absorb more energy than those that deform only elastically.

- The proposed dimensions of the order of 100 to 200 mm width and length should be suitable.

4. Experimental details

4.1. Overview

A test system was designed and constructed to perform impact tests on alternative protection systems. The system uses a drop weight onto a flat steel anvil, and is similar to that specified within the Beta Standard for Horse riders' Body and Shoulder Protectors [1]. The acceleration of the impactor and the load on the anvil are recorded electronically.

Curved plate specimens were manufactured from aluminium and plastic, and tested as single plates and as multiple plate assemblies. A commercial foam jacket was also tested in the same system.

4.2. Drop test system

The drop weight and load cell system are very similar to those specified in Section 6.5 of the Beta standard [1]. However to enable plate type specimens to be tested a larger flat anvil was used, rather than the smaller curved anvil specified in the Beta standard. The system, shown in Figure 4.1, consists of an 80mm diameter, 5kg impactor mounted on a sliding track. The test specimen is placed on a flat steel base which is clamped to a load cell (Kyowa LU-2T #AF 4025, maximum 20kN) and preloaded to approximately 10kN. An accelerometer (Type PCB J353804 #5849, 500G maximum) is mounted on the impactor. The two channels of data are recorded using Labview data acquisition software and an analog to digital data acquisition card on a personal computer. Most tests were performed using a sampling rate of 5000 Hz. All equipment was calibrated, and a number of tests were performed to evaluate and refine the test rig and instrumentation. The maximum drop height used in the tests was 1000mm, corresponding to the 50J energy required by the Beta standard for Class 2 body protectors (Section 5).
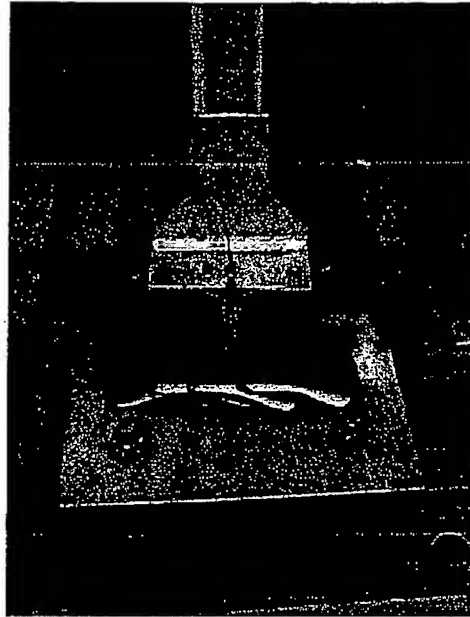
Figure 4.1 Impact test system

A high speed video system was hired to enable impact events to be recorded at a rate of 250 frames per second and a shutter speed of $^1/_{500}$ second. Each impact event was recorded from the high speed system onto a conventional digital video recorder at a rate of one frame per second. The system also enabled still photographs to be recorded at different stages of the impact.

4.3. Specimen manufacturing

A set of curved plates were machined from commercially available PVC drainage pipe. These plates had dimensions of approximately 150 long, 90mm wide, 3.1 $^+/.$ 0.1 mm thick, and a height of 15mm. Figure 4.2 shows a typical plate. Aluminium plates of similar dimensions, but a thickness of approximately 1.2mm, were also manufactured by bending flat sheet over a steel mandrel.

Figure 4.2 Curved PVC plate

To simulate an assembly of multiple plates four specimens were manufactured to shapes specified by Rhumbline (C1L3, and three of R2L3). These were fabricated from the same type of PVC material as the single plates, and had a final thickness of 3.2 $^+/_-$ 0.1 mm A heat gun was used to thermally form the required shapes. Rhumbline supplied material sleeves to locate the plates in the correct positions. Figure 4.3 shows the plate assembly in the sleeve.
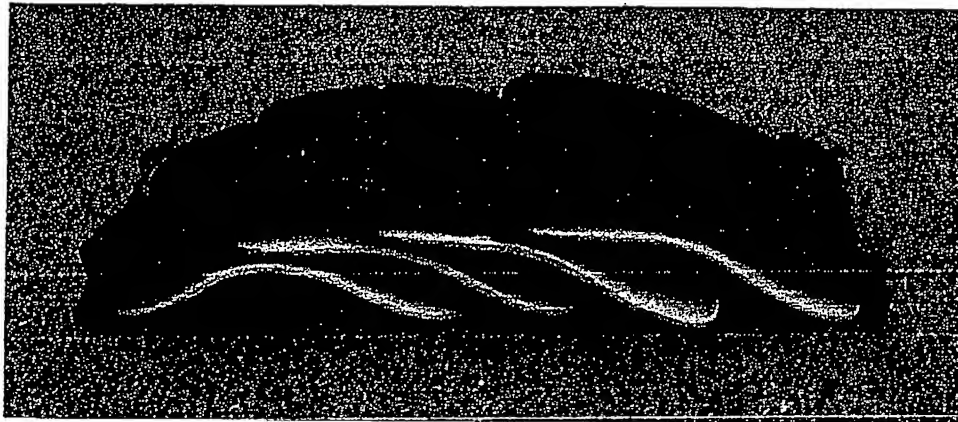

Figure 4.3 Assembly of multiple plates

4.4. Experimental programme

The first set of tests performed was on the curved aluminium plates. These permanently deformed to be flat at only low drop heights, so did not provide any meaningful results.

Single curved plates were tested at drop heights of 250, 400, 450 and 500mm. At drop heights of greater than approximately 450mm the plates appeared to compress fully, with a sudden increase in load.

The multiple plate system was tested at drop heights of 250, 500, 750 and 1000mm. Several tests were performed at each drop height. Tests were also performed with the plate assembly shifted sideways relative to the impactor so that 1, 2, 3 or 4 plates were involved in the impact event.

Attempts were made to determine the pressure distribution under the multiple plates during the impact events using pressure sensitive film and carbon paper. Neither of these methods gave useful results. However it was possible to assess the movement of the plates during the impacts from the video recording.

An RS 2000 model BETA 2000 approved foam protection jacket was supplied by Rhumbline. This was tested in the impact system at drop heights of 250, 500, 750 and 1000mm.

5. Results

5.1. Single curved PVC plates

The single plate specimens had a relatively low impact force load of less than 500N for drop heights of less than 400mm, however as shown in Figure 5.1 there was a sudden increase in load at a drop height of 450mm. The load increased further at a drop height of 500mm, with a maximum load of approximately 4000N. Significant "ringing" of the test system accompanied the increase in load. Observations with the high speed video camera confirmed that the plates were deforming to be completely flat at drop heights of more than approximately 450mm, causing the sudden increase in load. Figure 5.2 shows the deformed shape of the plate at drop heights of 250 and 500mm. Despite the high impact loads and repeated tests there was no deterioration observed in the plates.
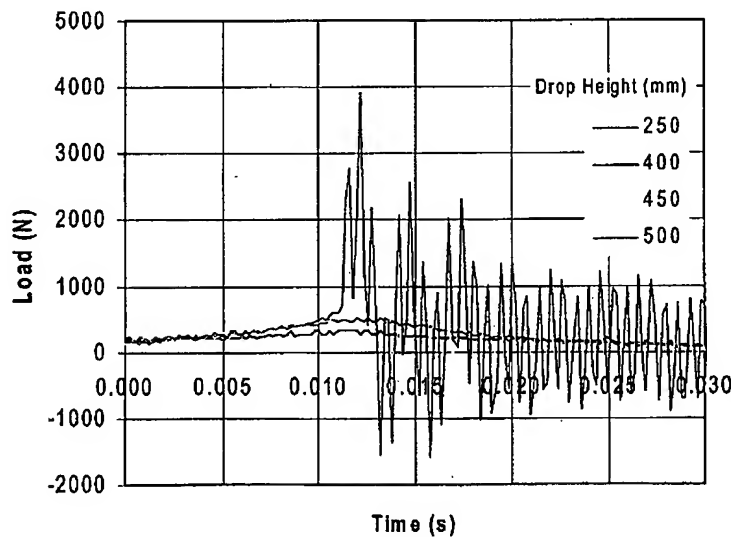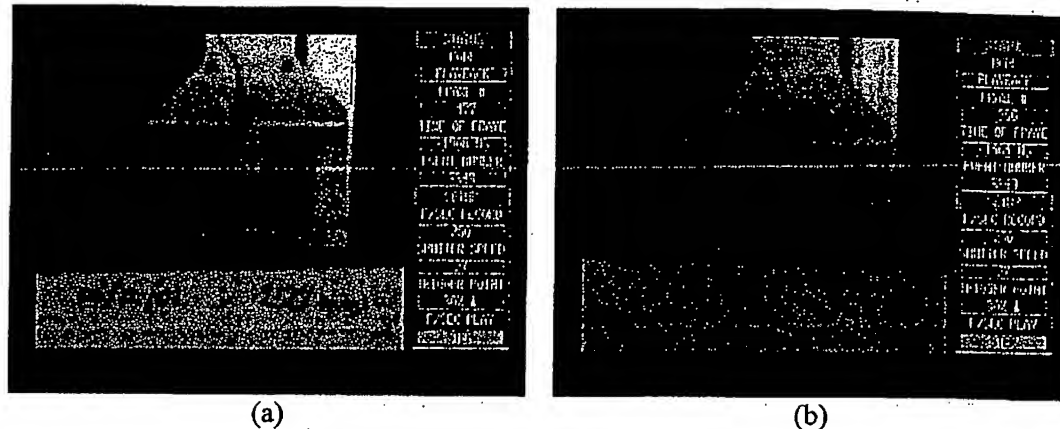

Figure 5.1 Load vs time for single plate at different drop heights

Figure 5.2 Single plate drop test images for 250mm (a)
and 500mm (b) drop heights

5.2. Multiple curved PVC plates

As shown in Figure 5.3, the multiple plates showed a progressive increase in impact load with drop height, reaching a maximum load of approximately 8000N for 1000mm drop height. The duration of the primary force impulse reduces with increasing drop height, from approximately 0.02s at 250mm to 0.005s at 1000mm. Figure 5.4 shows images of the impact tests at each drop height, confirming that the load is distributed over all of the plates.
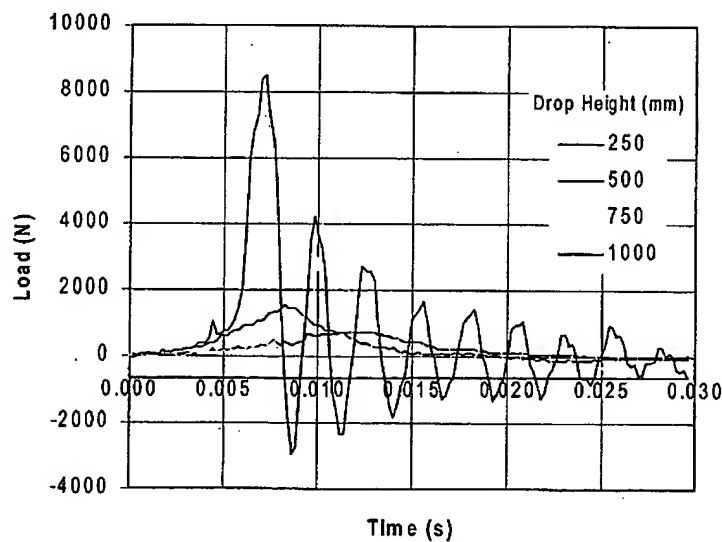

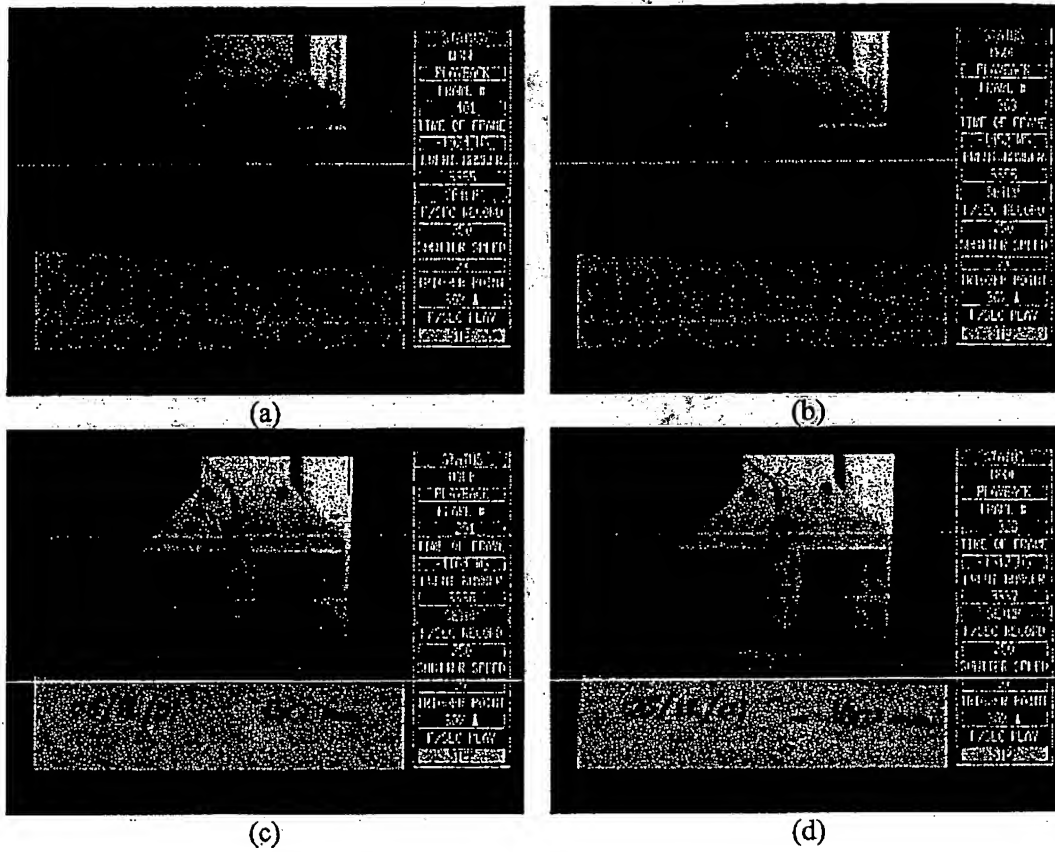Figure 5.3 Load vs time for multiple plates at different drop heights

Figure 5.4 Multiple plate drop test images for (a) 250mm, (b) 500mm,
(c) 750mm, and (d) 1000mm drop heights

Figure 5.5 compares force traces for repeated tests at 1000mm and 250mm drop heights. There is some variation in the peak load at the 1000mm drop height (from approximately 6400 to 9000N), however the general form of the graphs is very similar.
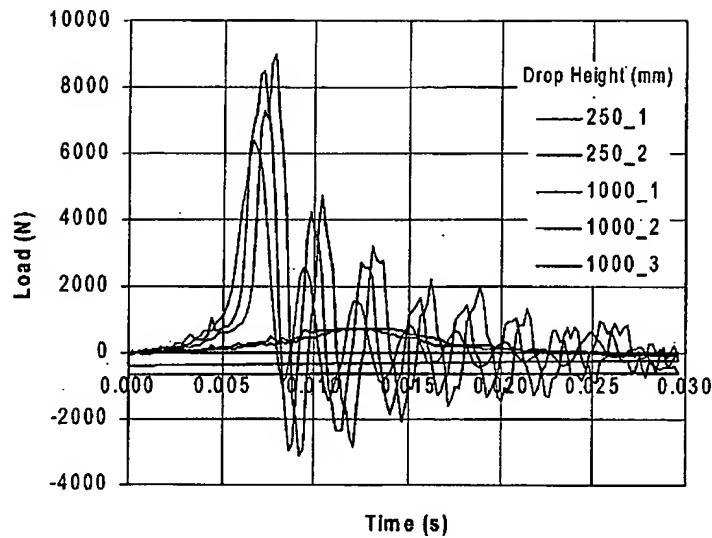
Figure 5.5 Repeated tests for multiple plates

Figure 5.6 shows results of tests performed with the plate assembly shifted sideways relative to the impactor so that a reduced number of plates were involved in the impact event. The corresponding impact images are shown in Figure 5.7. There were only relatively small increases in the peak load apart from the 80L position which only involved one plate in the impact. In this case, shown in Figure 5.7 (d), the plate appeared to deform completely flat, as for the equivalent test of a single plate.
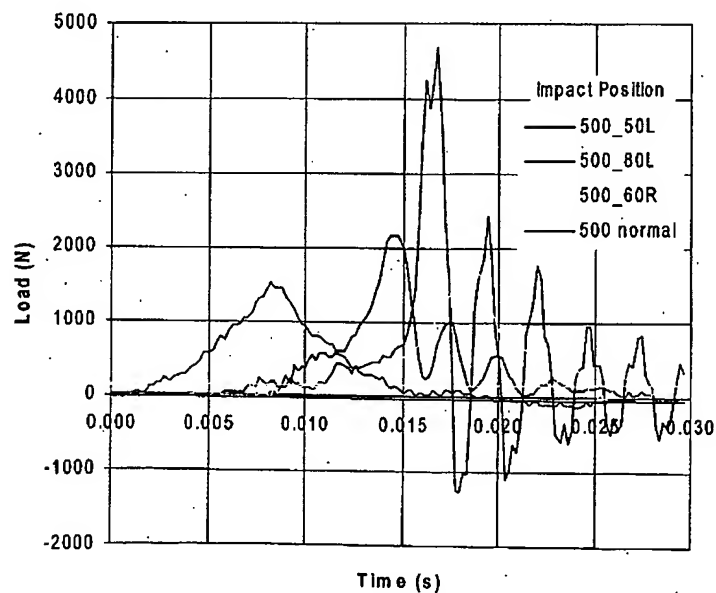

Figure 5.6 Effect of shifting position of multiple plates

Figure 5.7 Images of multiple plate impacts.
(a) Plates shifted 50mm left, (b) Normal position, (c) Plates shifted 60mm right, (d) plates shifted 80mm left

5.3. Beta 2000 approved foam jacket

The Beta 2000 approved foam jacket was tested at the same drop heights as the multiple plates. A different region of the jacket was used for each test to prevent cumulative damage. Figure 5.8 shows a graph of the resulting loads vs time. The maximum loads are relatively consistent at 1000 to 1500N for drop heights of 750mm or less, but increase to approximately 2200N for a 1000mm drop height. The duration of the primary force pulse is approximately equal at 0.01s for all drop heights. Figure 5.9 shows the impact images for each drop height. There does not appear to be any significant visual changes to the impact event at the different drop heights.
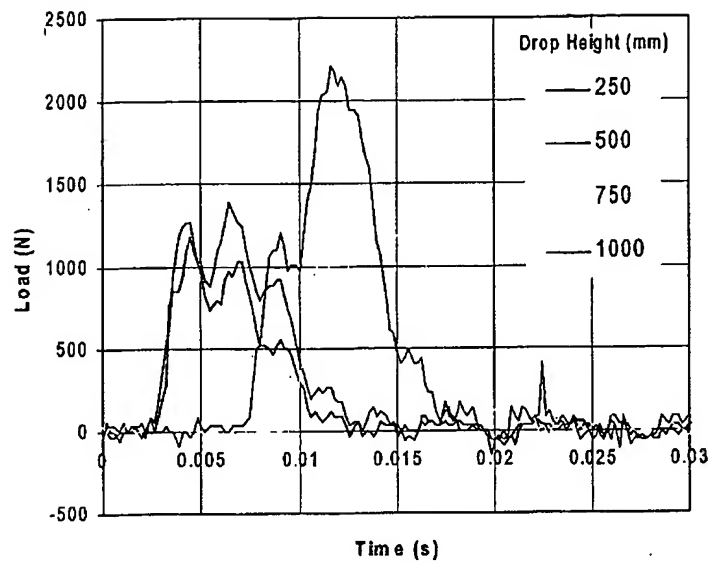
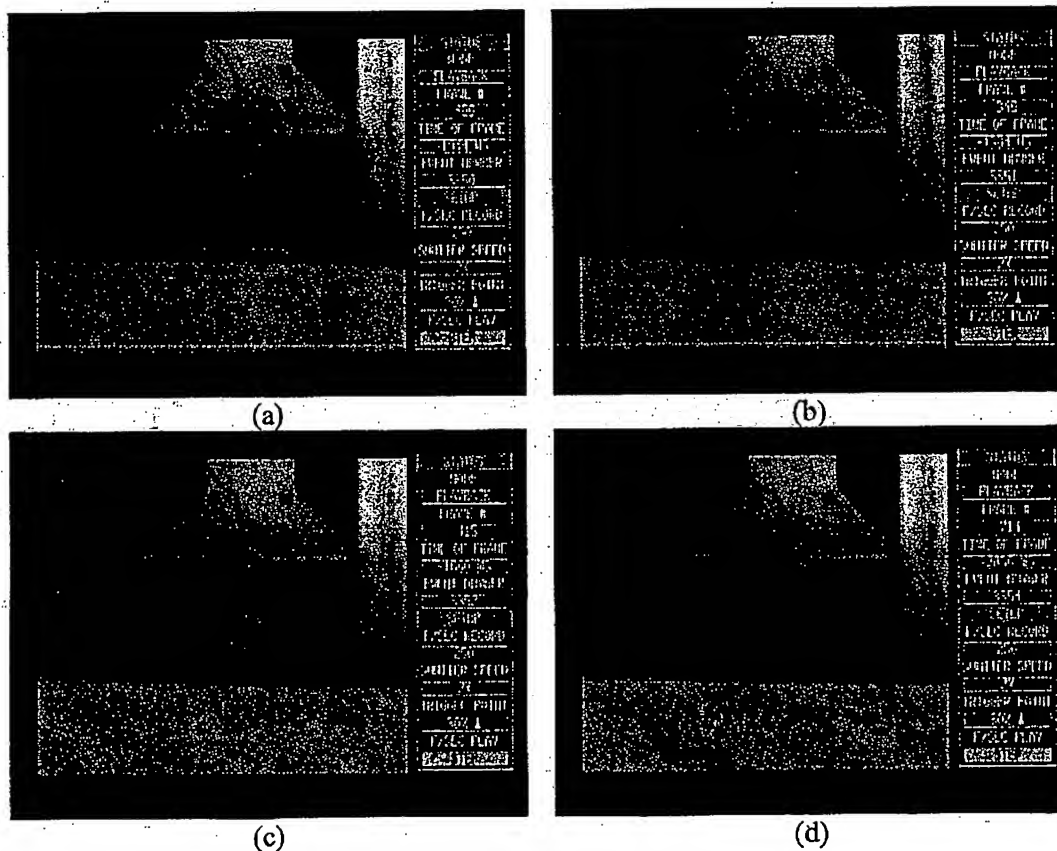Figure 5.8 Load vs time for foam vest at different drop heights

Figure 5.9 Foam jacket drop test images for (a) 250mm, (b) 500mm,
(c) 750mm, and (d) 1000mm drop heights

5.4. Overall comparisons

Figure 5.10 compares the force levels at different drop heights for the single plastic plates, multiple plastic plates, and the foam jacket for different drop heights. Linear interpolated trend lines have been added to the data points.
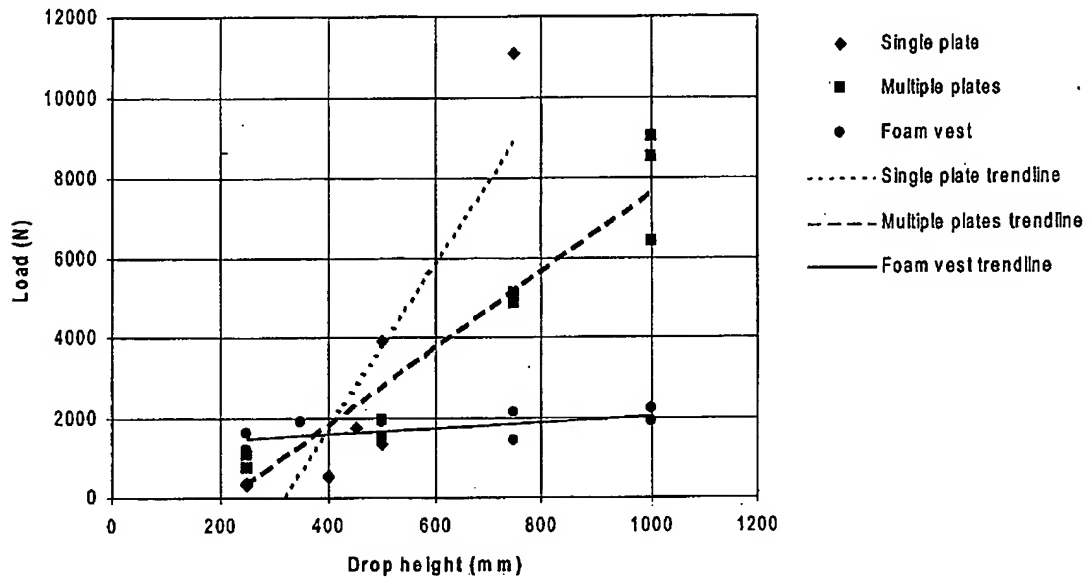

Figure 5.10. Peak force for different drop heights.

The Beta standard (Reference 1, Section 5.5) specifies that the average peak force recorded below the anvil should be below 4000N. The foam jacket meets this requirement, with a maximum load at 1000mm drop height (nominal 50J energy) being approximately 2000N. The single plate specimen performs well at low drop heights, but has a sudden increase in load and exceeds 4000N once it deforms flat at approximately 450 to 500mm drop height. The multiple plate system has a progressive increase in the load with increasing drop height, not exceeding 4000N until reaching a drop height of approximately 600mm. The peak load is largely a function of the plate geometry (particularly thickness and height), so it should be possible to design a plate system to meet relevant maximum load requirements.

6. Conclusions

Key findings of this study include:

- The multiple curved plate system investigated does successfully spread an impact force over area and time.

- The peak force for the multiple curved plate system increases and the force pulse duration reduces with increasing drop height.

- The peak force for the curved PVC samples is lower than that of a typical foam vest for small drop heights, but is greater at larger drop heights due to the plate samples compressing fully onto the test rig anvil or adjacent plates.

- For drop heights that do not cause the curved plates to compress excessively, the impact force is spread over a longer time scale than for the foam jacket.

- The plates should be manufactured from relatively thick (several mm), low modulus materials such as engineering polymers rather than thin high modulus metallic materials. The PVC material used for these tests showed no signs of deterioration after repeated tests.

- The dimensions for the plates proposed by Rhumbline Limited should be suitable.

These results suggest that the concept of using curved plates to distribute the impact loads does have good potential. However the materials and geometry of the plates need to be designed to ensure that the plates will not deform fully under the expected loads.

7. Future work

This study has demonstrated the feasibility of the multiple plate system for impact protection. Further technical work that would be required to develop this into a viable product includes:

- Investigating how the plates interact with a soft impact surface such as the human body.

- Quantifying the actual impact loads for the particular application.

- Developing a more refined design procedure to enable the geometry of the plate system to be accurately designed to accommodate the required loads. This could be achieved by transient dynamic finite element modelling.

- Determining the optimum material for the plates

- Confirming the design by impact testing of a full size plate system on a non-rigid body.

- Developing a cost-effective manufacturing method for the plates

8. References

1. The Beta Standard for Horse Riders' Body and Shoulder Protectors, Issue 1. 24.4.95, The British Equestrian Trade Association Ltd.

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